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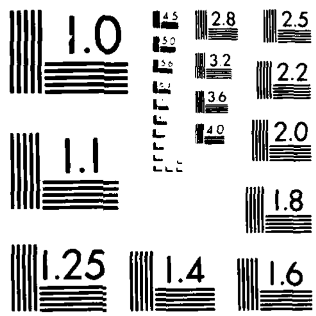

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ANTHROPOMETRY	AUSTRIA	CANADA	JAPAN	POLAND	THAILAND
DATABASE	BRAZIL	INDONESIA	NETHERLANDS	HUNGARY	US
ERGONOMICS	DENMARK	IRELAND	NORWAY	SPAIN	UK
HUMAN FACTORS ENGINEERING	FINLAND	ISRAEL	MEXICO	SOUTH AFRICA	
AUSTRALIA	FRANCE	ITALY	SWEDEN	SWITZERLAND	
INTERNATIONAL ERGONOMICS ASSOCIATION				WEST GERMANY	
				YUGOSLAVIA	

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report surveys the availability of ergonomic databases in the member countries of the International Ergonomics Association (which include the following: Australia, Austria, Brazil, Denmark, Finland, France, Canada, Indonesia, Ireland, Israel, Italy, Mexico, Japan, Netherlands, Poland, Hungary, Spain, South Africa, Sweden, Switzerland, Thailand, US, UK, West Germany, and Yugoslavia.) The goal of the survey was to identify sources of compiled human

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factors engineering or ergonomic data, including bibliographic as well as numeric data. A scan of published literature was accomplished and a letter of inquiry was sent to 107 individuals of whom 30 responded from 13 countries. Few formal data collections exist. Most ergonomic data remain embedded in the literature in which first reported. Briefly described are anthropometric and bibliographic databases that were identified. Chief among these were the files of the Ergonomics Information Analysis Center at the University of Birmingham in the UK; the Ergodata System at the University of Paris in France; and the PRODIS data collection at the Institut der Deutschen Wirtschaft in West Germany.

The title on the DD Form 1473 is correct for this report.
Per Mr. L. Wascher, HEL Field Office

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E R G O N O M I C S   D A T A B A S E S

from the member countries of the

INTERNATIONAL ERGONOMICS ASSOCIATION

Survey prepared for

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CONTENTS

S U M M A R Y

This report surveys the status of ergonomics databases in the member countries of the International Ergonomics Association. Most ergonomic data is available only in the literature where it was first reported. Few formal data collections exist and very few computerized databases were found in this survey. Handbooks and textbooks are still the main sources of collected ergonomics data.

Because scanning the published literature identified very few databases, a letter survey was sent to the mailing list for the International Ergonomics Association Newsletter. The survey requested help in identifying either computerized or manual databases. The responses to the letter survey verified that very few databases exist and identified a small number of intended future databases.

Anthropometry is the only body of information in which we found significant collections of international data currently available in computerized form. Most ergonomics data are still embedded in the published literature.

Recent use of the computer for ergonomics data gathering and data analysis has created the potential for previously existing limited studies of small populations to be extended into entirely new automated databases, but this potential has not been realized. After reviewing the strengths and weaknesses of available published data compendia and then describing the few large scale databases found in the survey, this report presents some examples of how existing data-gathering systems could be used to build new automated databases.

SURVEY OF ERGONOMICS DATABASES
from the member countries of the
INTERNATIONAL ERGONOMICS ASSOCIATION

This report surveys the availability of ergonomics databases in the member countries of the International Ergonomics Association. The goal was to identify compiled sources of human engineering data outside the United States. Because information about data collections in the United States is more readily available, U.S. collections are briefly discussed in this report only for purposes of comparison.

Most ergonomic data remain embedded in the literature where the studies were first reported. Few formal data collections exist and very few computerized databases were found in this survey.

Because scanning the published literature identified very few databases, a letter survey was sent to 107 people on the mailing list for the International Ergonomics Association Newsletter. The survey requested help in identifying either computerized or manual databases. The responses to the letter survey verified that very few databases exist and identified a small number of intended future databases.

Respondents from thirteen countries reported that no ergonomics databases were known to exist in their home countries. The results from those countries are as follows:

country	respondents	
Australia	4	
Brazil	1	
Britain	6*	
Canada	6	
China	2	
Ireland	1	
Japan	3	13 countries
Luxembourg	1	30 respondents
Netherlands	1	
South Africa	1	
Switzerland	2	
Thailand	1	
Uruguay	1	

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*Some British respondents did refer us to the Ergonomics Information Analysis Centre, University of Birmingham, but indicated that they did not know of any numeric databases in Britain.

Bibliographic databases expressly devoted to ergonomics are maintained in Britain, France, and Germany. Computerized databases on anthropometry are maintained in France and the United States. These collections are described in the section on LARGE SCALE DATABASES below. It was reported that Italy has a database on human reliability and one on normal vs. disabled postures, but thus far we have been unable to obtain details.

PUBLISHED DATA COMPILATIONS

Handbooks and textbooks are still the main sources of collected ergonomics data. Heinz Schmidtke, editor of the major German ergonomics text (Schmidtke 1981), has criticized textbook data, stating that it usually reflects approximate values and does not clearly explain the reliability and validity of the sources (Schmidtke 1984, p 7).

Döring has noted that much of the handbook data derives from single value experiments. Even though such experiments might be scientifically sound, the applicability of the results of such efforts is limited. In practice more than one variable acts on the human, and the quantitative effect of variable interaction is only known in a few cases (Döring 1984, p 65).

Kroemer thinks the precision of the available anthropometric data is adequate for most traditional applications. However, he sees the translation of static anthropometric data into dynamic information as problematic. No widely accepted methods are available to translate static standard data into functional measurements. Kroemer has expressed doubts that "current (often deterministic and overly simplistic) biomechanical models can represent the characteristics of the human body sufficiently, and [it is doubtful] if classical anthropometry can provide the information needed" for adequate modeling (Kroemer 1984, pp 104, 105, 108).

In a discussion of "Ergonomic Data for Console Design," Cushman agreed with Kroemer's skepticism, noting that static anthropometric measurements have historically been less than satisfactory for predicting people's dynamic reaching capabilities. Cushman points out that recommendations for console design are given in such handbooks as Van Cott & Kinkade (1972) and Woodson (1981), but that designers always need to pay attention to the conditions under which data were gathered, and apply corrections when needed. "The amount of effort that should be spent in modifying existing data so that they may be used for new applications will depend upon the criticalness of tasks that the operators perform and the consequences of operator errors" (Cushman 1984, p 155). Cushman identified a technical report by Ayoub and Halcomb (1976) as the most comprehensive review of console design recommendations. The authors provided a series of tables comparing over 40 books, scientific articles, technical reports, and standards. The authors clearly demonstrate that different investigators have used different reference points in defining console dimensions, thus illustrating the difficulties inherent in applying currently available measurements to specific problems (Cushman 1984, p 153-5).

Schmidtke identified similar limitations in a survey of ergonomics data for the design of body support. As an example, the literature on seating design reveals a plurality of reference points, and there is no consensus on what points to use when measuring a seat (Schmidtke 1984b, p 159).

The literature on control layout contains drawbacks similar to those found in the console dimension literature and the seating literature. Many good handbooks present what is known about such issues as control design, relative placement, and required association with displays, e.g., Van Cott & Kinkade (1972), McCormick (1982), Kraiss and Moraal (1976), Hutchingson (1981), Woodson (1981), and Eastman Kodak (1983). However, those guidelines are based mostly on experience. Less research literature exists on control design than one might expect (Wierwille 1984, p 179-180).

Snyder has asserted that the handbooks provide adequate guidelines on visual displays for "simple printed materials, individual alarm indicators, simplified alphanumeric readouts, etc." However, computer controlled technologies have created new problems. Differences between emissive displays and reflective displays, color use and methods of production, and choices of methods for controlling dynamic displays are not yet well researched (Snyder 1984, pp 219,224-226).

Increasing automation has introduced new ways for people to use systems, and these interactions have not been studied in depth. Shaw and McCauley reviewed existing guidelines for "person computer dialogue" in a supplement to the Engineering Data Compendium being developed at the USAF Aerospace Medical Research Laboratory. They found "a serious lack of empirical support for most of the guidelines that have been recommended for person-computer dialogue" (Shaw & McCauley 1985, p 10). [See the description of the USAFAMRL Integrated Perceptual Information for Designers (IPID) project below.]

Döring claims that increasing system complexity and automation will require a "system ergonomics" approach to human engineering. He emphasizes the shift from human as actor to human as monitor. "Instead of predominantly perceptual-motor tasks which personnel had to perform previously, operators now are increasingly involved with monitoring, management and decision tasks." System ergonomics will require either "human operator models" describing human capabilities such as control behavior, or network models in which "the human task performance is part of a network of system functions" (Döring 1984, pp 65,71).

Sound "system ergonomics" will require reliable information on human performance. Meister, in a review of past efforts to establish human performance data banks, offers four reasons for the lack of collated data collections on performance.

1) Interest, and therefore funding, for data collections has been confined to a few human reliability researchers.
2) Aggregating data is difficult because it has been gathered under different conditions and uses different measures.
3) Much of the available data on performance gives information only for the extremes of the continuum, because researchers have tested hypotheses that were more easily examined by testing extreme values.
4) Information from behavioral studies is often useless because it is neither job oriented nor directly applicable to real world issues.

Meister notes further that an established taxonomy of human tasks is necessary before a human performance database can be successfully organized. Thus past efforts have been restricted to the development of human reliability databases within narrow performance contexts (Meister 1982, p 722-726).

Fleishman, Quaintance and Broedling, in Taxonomies of Human Performance, (1984) have reviewed various methods for classifying tasks in order to "tie together several areas of basic and applied psychology." Their survey identified various taxonomies using the following task or human attributes:

-Ability Requirements
-Task Characteristics
-Criterion Measures
-Information-Theoretic Requirements
-Task Strategies

The candidate taxonomies were measured against three main goals:

1) ability to transform into a measurement system
2) potential for evaluation on reliability, validity, and utility
3) potential for translation into an indexing system to classify a wide variety of studies from the available literature.

Before this book there was no comprehensive summary of the various schemes for classifying task performance. This survey is useful because it brings together efforts from experimental psychology, personnel psychology, psychometrics, training research, and systems design.

Fleishman, et al. describe a preliminary attempt to build a database of previous research findings in order to test whether or not generalizations from the data improve with different methods of classifying and organizing the data. While they found performance classification to be "in its infancy," a number of the schemes they found, or invented themselves, do have the potential to improve predictions of performance -- whether by organizing an understanding of task requirements or by analyzing ability requirements.

Topmiller, Eckel, and Kozinsky (1982) provided a review of human reliability databanks in the United States. Drawing upon the previous comparison, Comer, Kozinsky, Eckel, and Miller (1983) designed a human reliability databank for nuclear power plant operations that is essentially an extension of Swain and Guttman's previous effort (1980). Comer, Donovan and Gaddy (1985) describe an operational test of the design for the nuclear power plant Human Reliability Data Clearinghouse. The Clearinghouse will publish and update a Human Reliability Data Manual.

The most recently published compendium of ergonomic data is the fourth edition of the _Kleine Ergonomische Datensammlung_ (KED). This "small ergonomics dataset" is formatted like the _US Army Human Engineering Design Data Digest_. The KED is a compendium of information about the German civilian population, including adult anthropometry and its application to standing and sitting workstation design. Data on displays, controls, vibration effects, and strength and lifting capacities are provided. VDT workstation design criteria are provided for screen, keyboard, table, chair, ventilation, lighting, and noise. Some of the DIN standards applicable to ergonomics are included, and appropriate references are given to the German occupational safety and health act.

LARGE SCALE DATABASES

Anthropometry is the only body of information in which we found significant collections of international data currently available in computerized form. Most ergonomics data are still embedded in the published literature.

Many of the large online engineering bibliographic databases cover subsets of the ergonomics literature. However, each of these bibliographic files has its own purpose and none of these sources provides comprehensive coverage of ergonomics. The Ergonomics Information Analysis Centre at the University of Birmingham, the French ERGODATA system at the University of Paris, and the PRODIS data collections at the Institut der deutschen Wirtschaft have bibliographies devoted solely to ergonomics.

Anthropometry is the only type of data found to be available in large computerized collections. Both the French ERGODATA and Anthropology Research Project, Inc. have significant international populations among the subjects.

ERGONOMICS INFORMATION ANALYSIS CENTRE

The Ergonomics Information Analysis Centre at the University of Birmingham, England, produces Ergonomics Abstracts, a quarterly publication of Taylor and Francis Ltd. of London. Since 1968 Ergonomics Abstracts has reviewed the international literature on man-machine systems and human factors of the physical environment. The journal includes approximately 3000 abstracts yearly. In order to examine the international content of the database, we analyzed the journals scanned. In 1980, the editors included 155 journals published in sixteen different countries. By 1985 the numbers had grown to 266 journals from twenty-one countries. This growth had been tempered by 1986, when 236 journals from nineteen countries were selected. See Appendix One for the 1986 list of journals.

Beginning with January, 1986 the abstracts are being deposited in a computerized database using Revelation, a relational database management system. Revelation will operate on most IBM compatible machines. A new classification scheme accompanies this computerization (see Appendix Two). The new scheme is divided into twelve main sections. There are sixty-five first-level headings which are further split into three levels, resulting in a current total of 564 headings. The complete listing of an abstract will be under whichever of these 564 headings most closely represents its primary classification term. Health and Safety topics are not covered in detail due to the presence in Britain of an online database sponsored by the Health and Safety Executive.

An applications cross-reference list, which contains identification numbers of the abstracts under the appropriate application terms, is included at the end of each quarterly issue. The staff at Birmingham plans to transfer the files for the past five years into the new database.

Several other services are offered by the Birmingham Ergonomics Information Analysis Centre. Specially requested bibliographies may be compiled from reference terms or subjects identified by the user. A list of currently available bibliographies is included here. (See Appendix Three.) Although the quarterly issues of Ergonomics Abstracts say that the Centre will loan any reports, periodicals, or articles included in the abstracts journal, this is not correct. However, the Centre will provide established data by telephone for the solution of applied problems. Members of the Centre's staff are available on a per day basis for on-site visits if the solution to the problem requires more than factual information.

NORTH AMERICAN ERGONOMICS INFORMATION ANALYSIS CENTER

The North American Ergonomics Information Analysis Center, located at the State University of New York at Buffalo, can provide computerized access to the published contents of Ergonomics Abstracts from 1974 through 1980. Current intentions are to marry these back files to the files being computerized at Birmingham. EARS (Ergonomics Abstracts Retrieval System) is the search and retrieval system designed to access this database. Using an inverted file organization and implemented on a CDC/Cyber, EARS performs combinations of searches and limited searches, as well as some editing functions. The files for 1974-1980 contain 35,000 abstracts. For more detail on EARS see Ramesh and Drury (1986).

ERGODATA

This French database is produced by Alex Coblentz and his coworkers at the Laboratoire d'Anthropologie Appliquée, Université Paris V. [This description is based on the presentation by Regis Mollard at the Stockholm Congress on Work With Display Units, May, 1986, (Coblenz 1986).] The databank is promoted as a tool for designers of products and equipment as well as researchers. The services offered are divided into five groups.

1. The Human Biometry Data Bank

The human biometry database for statistical analysis of human biometric and ergonomic data consists of two parts.

The first part contains over 4,000,000 individual anthropometric measurements of 45,000 subjects, gathered over the last 30 years on a large number of world populations. Although we do not yet have specifications of the exact populations or measures available on each group, the data cover the following:

general demographics:
age, sex, nationality, socio-professional categories

anthropometry:
human body measurements, space requirements measurements of the subjects, whether dressed or not, seated or standing

biostereometrics:
data recorded in a three-dimensional space

biomechanics:
measures for access and motion possibilities, and for muscular strength

human body dynamics:
measurements of inertial segmental and characteristic masses

physiological data:
visual and auditory acuity

The system is designed to help researchers, designers, manufacturers, ergonomists, and doctors deal with numerous

ergonomic problems involving morphological measurements and the variability of populations.

The second part of the ERGODATA biometry databank contains aggregate data derived from the published literature. The data includes 4,000,000 subjects from 88 nations. Again, we do not yet have specifications on the populations and measures taken, but the collection does include some strength data and some three-dimensional data, e.g., face shape variability useful for designing safety masks.

2. The Ergonomics Documentary Unit

The Documentary Unit is divided into two parts, a bibliographic database and a collection of synthesis sheets.

The bibliographic section includes abstracts of all types of publications from 24 nations. The majority are in English and address:

work and environment physiology
human factors studies
staff selection and medical observation
man-machine systems
work psychology
professional health and safety
biometrics
biomechanics
bioengineering
safety equipment
staff formation and assessment

The synthesis sheets are in development and are intended to provide structured and pre-analyzed information. Much of this analyzed information will be easily accessible in tables, standards, or recommendations and figures.

3. The Computer Aided Design Unit

Anthropometric and biomechanical data from the human biometry data bank are incorporated into a three-dimensional human body modeling system using the CAD software "EUCLID." We do not yet have much specification of the character of this system.

4. The Expert Consulting System (under development)

This system will use an inference process based on first order predicate calculus, with forward and backward chaining. The knowledge representation is intended to combine a frame-based

and a production rule system. In addition to drawing data from the biometry databank and the three-dimensional CAD system, the expert consulting system will also use two currently available modules which provide computerized determination of statistical models and optimal postures.

5. The Computerized Human Body Movement Catalogue (under development)

This catalogue of human body movement analysis uses the three-dimensional "VICON" system. The only information currently available involves three reach movements of the upper limbs of seated operators.

ANTHROPOLOGY RESEARCH PROJECT, INC.

The Anthropology Research Project located in Yellow Springs, Ohio is the principal United States center for the collection and analysis of human dimensions and for the application of these measurements to a variety of design problems involving clothing, equipment, and workspaces. The project originated with a 1950 Air Force survey and has been responsible for every sizable anthropometric survey of United States military personnel since that time. It has also been involved with several civilian surveys of adults and children.

The types of data collected are body sizes, mass distribution, joint range of motion, strength and reach capabilities, and functional dimensions for specific working positions. Body size information for hundreds of dimensions of the torso, head, face, and extremities is available. The numeric data are organized by survey and stored on tape. Cross references identify the dimensions measured on each survey. The information may also be organized by sex, age, nationality, specialized size categories, or occupational specialties. The collection is updated continuously.

The database contains information from the majority of current anthropometric surveys of U.S. populations. The Anthropometric Source Book (NASA Reference Publication 1024, 1978) contains much of the original data and may be used as a guide to the databank. Data from over fifty foreign studies involving twenty-three different nationalities are included. A partial listing of the international surveys added since the publication of the NASA Sourcebook includes:

population	date	subjects	dimensions
English Guardsmen	1975	100	60
English Transport Corpsmen	1976	161	60
United Kingdom Gurkhas	1976	36	60
Hong Kong Chinese Military	1976	76	46
Israeli Aircrewmen	1981	133	63

See Appendix Four for a listing of the international contents.

PRODIS
(PROjekt Dokumentations- und Informations- System)

As part of a West German government program to improve working conditions, the Insitut der deutschen Wirtschaft has, since 1981, been collecting and storing ergonomics data from literature research reports and from corporate studies on workplace improvement. The PRODIS database evolved from a six stage process of data gathering and analysis and is approximately equivalent to 120,000 pages of text. We do not yet have many specific details on the substance of these texts.

Contents of the PRODIS database:

1. Industrial projects

-Interviews
This full text section contains documentation of specific measures taken by firms to improve the quality of working life. Detailed descriptions and practical advice supply ideas for problem solving in industry.

-ERFA
Measures taken to improve the design of work and reported in response to a PRODIS questionnaire are documented. The text contains the title of the measure but provides no detailed description.

-Industrial inspectorate
Short descriptions provide examples for industrial problem solving as reported by the industrial inspectorate offices.

2. Practical aids

-Information packages
Information on specific topics has been prepared by PRODIS specialists and is available in a complete text format. Entire reports or relevant chapters may be selected. Such topics as VDU's, lighting, mechanical vibrations, flexi-time, and climate are available.

3. Short accounts of research projects

-Research reports
A variety of research reports are documented in summary form.

-Fodok
Research reports from the Bundesanstalt für Arbeitsschutz (Federal Offices for Work Safety) are stored here.

-BMFT
Reports on all projects supported by the Bundesministerium für Forschung and Technologie (Federal Ministry for Research and Technology) concerning the quality of working life are available.

4. Literature references

-Books
Important books covering the work sciences are summarized.

-Journals/Journal articles
Articles in professional journals are summarized.

-Grey literature
Publications from various institutes, firms, professional organizations, etc. are summarized.

-Recommendations/Requirements
The most important legal requirements, standards, or recommendations covering a particular topic are summarized. Standards are referred to but not stored.

-New publications
Author and title of newly published specialist books are given. No summary of text is available.

-Litdok
Title and author references to articles from specialized journals which are available from the Bundesanstalt für Arbeitsschutz are listed without summaries.

5. Others

-Seminars

Summary descriptions are given of all courses offered in the Federal Republic of Germany which deal with improving the quality of working life.

-Accident prevention requirements

This section documents all accident prevention requirements (UVV) for industrial concerns and is offered in cooperation with the Hauptverband der gewerblichen Berufsgenossenschaften (Main Offices of Industrial Occupation Associations).

6. Special file for wage agreements

Compiled by the Federation of German Employers, this file contains master wage agreements, basic wage agreements, basic salary agreements, protective agreements for rationalization, and payments to induce capital saving. It is continuously updated.

Original plans called for the database to operate on the host system FIZ Technik of the Gesellschaft für Information und Dokumentation MBH (GID), Frankfurt, but we have not been able to verify actual access procedures.

Appendix Five provides a brief survey of the types of information available in the PRODIS database. Appendix Six lists the PRODIS controlled vocabulary.

USAFAMRL IPID

The US Air Force Aerospace Medical Research Laboratory project IPID (Integrated Perceptual Information for Designers) is the most aggressive database activity identified in the present survey. Beginning with the Handbook of Perception and Human Performance, edited by Boff, Kaufman and Thomas, published by Wiley (vol. 1 released May 1986 and vol. 2 to be released in mid-July), USAFAMRL is recompiling and extending the data into a format intended for use by design practitioners ("Engineering Data Compendium: Human Perception and Performance").

For the Handbook of Perception and Human Performance, the literature on sensation, perception, human information processing, and performance were reviewed for potential value in the design of controls and information displays. Forty-five technical subareas were selected for detailed treatment. Sixty-six subject matter experts wrote the forty-five chapters, organized into eight sections:

Theory and Methods
Basic Sensory Processes I
Basic Sensory Processes II
Space and Motion Perception
Information Processing
Perceptual Organization and Cognition
Human Performance

See Appendix Seven for the table of contents and preface from the Handbook of Perception and Human Performance. The preface explains both the organization and intention of the work.

The "Engineering Data Compendium: Human Perception and Performance," is expected to go to press in November, 1986. The compendium will add to the data contained in the handbook and reformat it for use by designers. In addition to the handbook contents, the following areas were reviewed for additional information beyond the Handbook contents:

Information coding, portrayal and format
Target detection, recognition and identification
Automation and allocation of functions
Person-computer dialogue
Feedback, warning and attentional directors
Human performance reliability
Controls
Vibration and visual displays

See Appendix Eight for the table of contents, preface and introduction from the prototype "Engineering Data Compendium." The introduction gives a concise description of the validation techniques used for the contents and the "human factoring" of the data presentation.

The next phase of the USAFAMRL IPID project will develop a "Designer's Associate," an artificial intelligence based version of the Engineering Data Compendium, and will establish CSERIAC (Crew Station Ergonomic Information Analysis Center) to keep the Compendium updated.

DATA ACQUISITION SYSTEMS

Recent use of the computer for ergonomic data gathering and data analysis has created the potential for previously existing limited studies of small populations to be extended into entirely new automated databases, but this potential has not been realized. To illustrate this potential, this section describes three sample projects that could be used to construct databases.

Ohio State University Biomechanics

Rockwell and Marras at Ohio State University are using an IBM PC interactively with an ISAAC 2000 data acquisition system to collect biomechanical data (Rangarajulu, Marras & Rockwell, 1985). Data being collected are on the difference between motion and static exertion in the trunk, including loads due to muscle activity (EMG data on the trunk muscles) as well as torque from outside loads.

They are also monitoring people in the workplace, assessing people's actual movements (angles and velocities). Most past readings have been taken in the sagittal plane rather than in a dynamic mode. They agree that their system could be used to analyze data taken by others if the data are available on magnetic tape.

United States Olympic Committee

The United States Olympic Committee Sports Medicine Program has a division of Biomechanics and Computer Services which analyzes information on athletic performance in order to improve techniques, minimize injuries, and design sports equipment.

The data are collected by a variety of methods. High speed 16mm films of athletes in action are analyzed on a computerized digitizing system. Graphic and numerical output are generated from software programs developed by the laboratory staff on Data General hardware. High speed videography provides coaches and athletes frame-by-frame viewing of selected performances for immediate technical corrections. Computer analysis of the filmed athletes' movements is also available. Force platform studies consist of placing a rigid instrumented platform on an athletic surface in order to measure the ground reaction forces. Electromyography allows researchers to synchronize muscle pattern data with videotaped movement in order to monitor muscle activity. Electronic Motion Analysis also allows movement

patterns from any point on the body or athletic equipment to be displayed in real time on a computer screen. Researchers are able to collect data on athletes engaged in various running or walking activities by using electrodynogram technology, in which sensors attached directly to the feet feed information into a portable pack worn by the athlete.

University of Waterloo, Department of Kinesiology

Robert W. Norman in the Department of Kinesiology at the University of Waterloo, Ontario, Canada has software packages for static and dynamic human motion analysis. All of the software is written in BASIC. These packages include WATBAK, WATEMG, BIOMECH, and COMONS.

WATBAK provides a sagittal plane static analysis of moments of force at various body joints including the low back. It runs on an HP9845 or IBM PC and may be used to analyze any job that involves manual manipulation of loads such as in the mining industry, municipal government (e.g., trash handlers, parks and recreation employees), or health care settings (e.g., people handling patients in residences for the elderly). There are few inputs for each subject and the output is specific to the person analyzed.

WATEMG is a versatile EMG signal processing package which runs on an HP9845. It is currently used for load handling problems and muscle fatigue in military and industrial settings. The program requires analog digital conversion of an electromagnetic signal and automated entry. The output is similar to an electrocardiogram, with the degree of muscle force being depicted on a strip chart recorder.

BIOMECH provides a two-dimensional, sagittal plane dynamic analysis of virtually any form of human motion. It provides complete kinematic and kinetic analysis which includes mechanical energy and power outputs, joint moment and reaction forces, and body segment and total body momentum. Used in pathological walking analysis and testing of artificial limbs, the program analyzes movement by manipulating input from a filmed digitizer.

COMONS (COmputerised MOvement Notation System) is a series of programs developed to record and manage movement record files effectively on an IBM PC. The software allows the user to create symbols to represent various movement aspects and to create and edit a movement chart. Data can be entered by instrumentation or through an interactive program. The operator views a video image of a subject one frame at a time, then estimates angles on specifically targeted joints. This training could be used, for example, to enhance a physical therapist's recognition of local motion changes when working with disabled patients. Computer records could monitor these changes.

CONCLUSION

Most ergonomics data are still embedded in the published literature. Literature reviews in technical reports, handbooks, and textbooks are still the main sources for compiled data. Only a few computerized databases already exist.

Anthropometry is the only body of information in which we found significant collections of international data currently available in computerized form. Both the Anthropology Research Project, Inc. and the French ERGODATA system contain international populations, but neither can yet be accessed online.

The bibliographic databases are presently in the process of being computerized. When this automation is achieved, these tools should allow more effective management of the international ergonomics literature, and easier location of published data.

Comparisons and evaluations of the data will then be required if similar studies are to be compiled into either hardcopy compilations or computerized databases.

We do not yet have sufficient detail on the bibliographic contents of the PRODIS and ERGODATA collections to compare them with the contents of Ergonomics Abstracts.

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ACM Transactions on Office Information Systems
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American Journal of Psychology
Annales des Mines
Annals of Human Biology
Annals of Occupational Hygiene
Annals of Physiological Anthropology
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BSI News
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ESA Bulletin
ESA Journal
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Foundry Trade Journal

GEC Journal of Research
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Human Factors
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Human Movement Science
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IBM Systems Journal
ICL Technical Journal
IEEE Computer Graphics and Applications
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IEEE Transactions on Medical Imaging
IEEE Transactions on Pattern Analysis and Machine Intelligence

IEEE Transactions on Professional Communication
IEEE Transactions on Software Metrics
IEEE Transactions on Systems, Man and Cybernetics
IEEE Transactions on Vehicular Technology
IEE Proceedings F—Communications, Radar and Signal Processing
IFAC Information Bulletin
IIE Transactions
Industrial Engineering
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Journal of General Psychology
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Journal of Human Ergology
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Journal of Motor Behavior
Journal of Navigation
Journal of Occupational Behaviour
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Journal of Occupational Psychology
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Journal of Sound and Vibration
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Zeitschrift fur Verkehrssicherheit
Zentralblatt fur Arbeitsmedizin, Arbeitsschutz, Prophylaxe und Ergonomie

1980 155 journals representing 16 countries
1985 266 journals representing 21 countries
1986 236 journals representing 19 countries

CLASSIFICATION SCHEME

ERGONOMICS

1. GENERAL
   - **1.1 Annual reports**
   - **1.2 Resources**
   - **1.3 Databases**
   - **1.4 Reviews**
   - **1.5. Standards, codes of practice, guidelines and recommendations**
   - **1.6 Legislation**
   - **1.7 History of ergonomics**
   - **1.8 Introduction of ergonomics**
   - **1.9 Education in ergonomics**
   - **1.10 Marketing of ergonomics**

HUMAN CHARACTERISTICS

2. PSYCHOLOGICAL ASPECTS
   - **2.1 Visual processes**
     - 2.1.1 visual detection and acuity, contrast sensitivity and visual field
     - 2.1.2 visual adaptation and pupil control
     - 2.1.3 visual accommodation and convergence
     - 2.1.4 eye and head movements
     - 2.1.5 visual perception of real scenes, pictures and faces
     - 2.1.6 visual perception of form, shape, angle, size and distance
     - 2.1.7 visual perception of texture and movement
     - 2.1.8 visual perception of colour and colour blindness
     - 2.1.9 visual illusions and after-effects
     - 2.1.10 monocular versus binocular vision
   - **2.2 Auditory processes**
     - 2.2.1 auditory sensitivity
     - 2.2.2 auditory perception
     - 2.2.3 monaural versus binaural hearing
   - **2.3 Cutaneous processes**
     - 2.3.1 touch and pressure sensitivity and perception
     - 2.3.2 pain sensitivity and perception
     - 2.3.3 temperature sensitivity and perception
   - **2.4 Taste and olfactory processes**
   - **2.5 Kinaesthetic and proprioceptive processes**
   - **2.6 Vestibular processes**
   - **2.7 Interaction between modalities**
   - **2.8 Time perception**
   - **2.9 Cognitive processes**
     - 2.9.1 search
     - 2.9.2 sensory memory
     - 2.9.3 short term memory and working memory
     - 2.9.4 long term memory and semantic memory
     - 2.9.5 knowledge representation
     - 2.9.6 imagery
     - 2.9.7 decision making and risk assessment
     - 2.9.8 problem solving and reasoning
     - 2.9.9 learning, skill development, knowledge acquisition and concept attainment
     - 2.9.10 language communication and comprehension
     - 2.9.11 reading
   - **2.10 Motor processes**
     - 2.10.1 movement organisation and motor programs
     - 2.10.2 simple movements
     - 2.10.3 complex movements
     - 2.10.4 tracking movements
     - 2.10.5 speech
   - **2.11 Human performance**
     - 2.11.1 reaction time and speed of performance
     - 2.11.2 errors, accuracy and reliability
     - 2.11.3 attention, time sharing and resource allocation
     - 2.11.4 performance strategies
     - 2.11.5 manual control
     - 2.11.6 supervisory control
   - **2.12 Behavioural and social processes**

3. PHYSIOLOGICAL AND ANATOMICAL ASPECTS
   - **3.1 Physiology of the nervous system**
     - 3.1.1 visual sensory system
     - 3.1.2 auditory sensory system
     - 3.1.3 other sensory systems
     - 3.1.4 autonomic nervous system
     - 3.1.5 brain function
     - 3.1.6 effector system
   - **3.2 Basic functions**
     - 3.2.1 cardiac processes

3.2.2 respiratory processes
3.2.3 metabolic processes
3.2.4 body temperature regulation
3.2.5 reproductive processes

3.3 Work capacity
3.3.1 static work capacity
3.3.2 dynamic work capacity

3.4 Anthropometry and biomechanics
3.4.1 static body measurements
3.4.2 dynamic body measurements
3.4.3 muscular strength and endurance
3.4.4 posture
3.4.5 simple movements
3.4.6 complex movements

PERFORMANCE RELATED FACTORS

4. GROUP FACTORS

4.1 Age
4.1.1 children
4.1.2 young adults
4.1.3 middle aged adults
4.1.4 elderly adults

4.2 Gender
4.2.1 male
4.2.2 female

4.3 Culture and ethnic group
4.4 Experience and practice
4.5 Trained versus untrained
4.6 Pregnancy
4.7 Regional and geographical differences

5. INDIVIDUAL DIFFERENCES

5.1 Intelligence
5.2 Ability
5.2.1 mental ability
5.2.2 physical ability

5.3 Personality, temperament and mood
5.4 Aptitude
5.5 Achievement
5.6 Attitude
5.7 Physical fitness
5.8 Laterality
5.9 Cognitive style
5.10 User's model, mental models and cognitive maps

6. PSYCHOPHYSIOLOGICAL STATE VARIABLES

6.1 Sleep
6.1.1 sleep loss
6.1.2 sleep pattern

6.2 Physiological rhythms
6.2.1 circadian rhythms
6.2.2 menstrual cycle
6.2.3 biorhythms

6.3 Arousal
6.4 Fatigue
6.4.1 visual fatigue
6.4.2 auditory fatigue
6.4.3 fatigue of other sensory modalities
6.4.4 mental fatigue
6.4.5 physical fatigue
6.4.6 motor and postural fatigue

6.5 Fear, anxiety and emotional state
6.6 Nutrition and diet
6.7 Drugs
6.7.1 smoking
6.7.2 alcohol

7. TASK RELATED FACTORS

7.1 Mental workload
7.2 Physical workload
7.3 Stress
7.4 Monotony and boredom
7.5 Vigilance
7.6 Knowledge of results, feedback and feedforward
7.7 Sensory deprivation
7.8 Personal isolation

INFORMATION PRESENTATION AND COMMUNICATION

8. VISUAL COMMUNICATION

8.1 Design of alphanumeric characters
8.1.1 size of characters
8.1.2 shape of characters
8.1.3 colour of characters

8.2 Design of graphics
8.2.1 pictorial symbols
8.2.2 graphs
8.2.3 charts and maps
8.2.4 pictures
8.2.5 3-dimensional graphics

8.3 Coding of information
8.3.1 coding by size
8.3.2 coding by shape
8.3.3 coding by brightness and contrast
8.3.4 coding by blinking
8.3.5 coding by colour
8.3.6 coding by alphanumerics, words and abbreviations
8.3.7 coding by position and configuration
8.3.8 coding by graphic symbols, icons and pictograms
8.3.9 coding by mnemonics
8.3.10 analog versus digital coding

8.4 Information layout and format
8.4.1 sequencing of information
8.4.2 information density, clutter and spaciousness
8.4.3 grouping of information

8.5 Labelling and headings
8.6 Windowing, scrolling and paging

DISPLAY AND CONTROL DESIGN

22.4.2 electroluminescent displays
22.4.3 plasma and vacuum fluorescent displays
22.4.4 light emitting diodes
22.4.5 liquid crystal displays
22.5 Headup and projected displays
22.6 Multifunction displays
22.7 Conspicuity aids
22.8 Signs
22.9 Status displays and boards
22.9.1 indicator lights

23. AUDITORY DISPLAYS
23.1 Auditory aids
23.2 Voice output and speech synthesis

24. OTHER MODALITY DISPLAYS
24.1 Tactile displays
24.1.1 braille devices

25. DISPLAY AND CONTROL CHARACTERISTICS
25.1 Display dynamics
25.2 Display quality
25.2.1 display brightness and contrast
25.2.2 display polarity
25.2.3 display colour
25.2.4 display stability
25.2.5 display flatness
25.3 Display layout
25.4 Control dynamics
25.5 Control layout
25.6 Display–control relationships
25.6.1 stimulus–response compatibility
25.6.2 population stereotypes
25.7 Paper versus screen

WORKPLACE AND EQUIPMENT DESIGN

26. GENERAL WORKPLACE DESIGN AND BUILDINGS
26.1 Large scale layout and plant layout
26.2 Floors, ramps, stairs, handrails and lifts

27. WORKSTATION DESIGN
27.1 Fit
27.2 Reach
27.3 Access and clearance
27.4 Personal space
27.5 Visibility

28. EQUIPMENT DESIGN
28.1 Machine tools
28.2 Hand tools
28.3 Consumer product design
28.4 Furniture
28.4.1 seating
28.4.2 work-surfaces
28.5 Vehicles
28.6 Supplementary equipment
28.6.1 document holders
28.6.2 limb supports e.g. foot rests, wrist & elbow supports
28.6.3 handles
28.6.4 ladders
28.6.5 equipment support

ENVIRONMENT

29. ILLUMINATION
29.1 Illumination levels
29.2 Illumination quality
29.2.1 daylight contribution
29.2.2 colour characteristics
29.2.3 colour describing systems
29.3 Layout for illumination
29.3.1 visual comfort zone
29.3.2 disability glare
29.3.3 discomfort glare
29.3.4 veiling and specular reflections
29.3.5 glare control
29.4 Design of illuminants

30. NOISE
30.1 Noise levels
30.2 Noise quality
30.2.1 intermittent noise
30.2.2 continuous noise
30.2.3 music-while-you-work
30.2.4 noise frequency
30.2.5 infrasound
30.2.6 ultrasound
30.3 Exposure to noise
30.3.1 auditory comfort
30.3.2 annoyance from noise
30.3.3 communication and masking in noise
30.3.4 temporary auditory threshold shift

31. VIBRATION
31.1 Vibration levels
31.2 Vibration quality

32. WHOLE BODY MOVEMENT
32.1 Whole body velocity
32.2 Whole body acceleration and deceleration
32.3 Motion sickness

33. CLIMATE
33.1 Temperature
33.1.1 low temperature
33.1.2 high temperature

33.2 Humidity
33.3 Air speed
33.4 Heat stress
33.5 Acclimatisation
33.6 Dehydration
33.7 Thermal comfort

34. ATMOSPHERE
34.1 Particles and gases
34.2 Static electricity
34.3 Ionisation

35. ALTITUDE, DEPTH AND SPACE
35.1 Air pressure
35.2 Hypoxia
35.3 Hyperoxia
35.4 Weightlessness
35.5 Disorientation

36. OTHER ENVIRONMENTAL ISSUES
36.1 General environment
36.2 Combined environments

SYSTEM CHARACTERISTICS

37. GENERAL SYSTEM FEATURES
37.1 System friendliness, usability and acceptability
37.2 System adaptability and flexibility
37.3 System facilities
37.4 System dynamics
37.5 System response time
37.6 System availability
37.7 System reliability
37.8 System security and integrity
37.9 System transparency
37.10 System performance and evaluation
37.11 System design and interface engineering

WORK DESIGN AND ORGANISATION

38. TOTAL SYSTEM DESIGN
38.1 Allocation of function
38.2 Design and development process

39. HOURS OF WORK
39.1 Shift work
39.2 Rest pauses and work duration

40. JOB ATTITUDES AND JOB SATISFACTION

41. JOB DESIGN
41.1 Job restructuring
41.1.1 job enlargement
41.1.2 job enrichment
41.2 Work organisation and sociotechnical systems
41.2.1 job rotation
41.2.2 autonomous work groups
41.2.3 team work
41.3 Job characteristics
41.3.1 pacing
41.3.2 repetitiveness and cycle time
41.3.3 job autonomy and user control
41.3.4 skill demands
41.3.5 workload demands
41.3.6 knowledge of results and feedback
41.4 Work context factors
41.4.1 pay and security
41.4.2 supervision and relationships with co-workers

42. PAYMENT SYSTEMS

43. SELECTION AND SCREENING

44. TRAINING

45. SUPERVISION

46. USE OF SUPPORT
46.1 Use of instructions
46.2 Use of manuals
46.3 Use of within system documentation
46.4 Use of human support
46.5 Use of work procedures

47. TECHNOLOGICAL AND ERGONOMIC CHANGE
47.1 Resistance to and effects of change
47.2 Introduction and strategies for introduction of change
47.3 Evaluation and cost benefits of change

HEALTH AND SAFETY

48. GENERAL HEALTH AND SAFETY
- **48.1 Surveys, statistics and analysis**
- **48.2 Data collection and recording**
- **48.3 Causation models**
  - 48.3.1 general accident models
  - 48.3.2 risk taking
  - 48.3.3 accident proneness
  - 48.3.4 epidemiology

49. ETIOLOGY
- **49.1 Individual differences**
- **49.2 Information and communication design**
- **49.3 Display and control design**
- **49.4 Workplace and equipment design**
- **49.5 Environmental design**
- **49.6 Chemical hazards**
- **49.7 Work design and organisational factors**

50. INJURIES AND ILLNESSES
- **50.1 Injuries resulting from accidents**
  - 50.1.1 Injuries from falling, slipping and tripping
- **50.2 Effects on the visual system**
- **50.3 Effects on the auditory system**
- **50.4 Effects on other senses**
- **50.5 Effects on brain function**
- **50.6 Psychological disorders**
- **50.7 Effects on the cardiovascular system**
- **50.8 Effects on the respiratory system**
- **50.9 Effects on the digestive system**
- **50.10 Effects on the reproductive system**
- **50.11 Effects on the skin**
- **50.12 Effects on the musculo-skeletal system**

51. PREVENTION
- **51.1 Health and safety propaganda**
- **51.2 Education, training and safety programmes**
- **51.3 Selection and screening for health and safety**
- **51.4 Supervision for health and safety**
- **51.5 Information and communication design for health and safety**
- **51.6 Display and control design for health and safety**
  - 51.6.1 emergency and warning devices
- **51.7 Workplace and equipment design for health and safety**
- **51.8 Work design and organisation for health and safety**
- **51.9 Protective clothing**
  - 51.9.1 headgear
  - 51.9.2 handgear
  - 51.9.3 footgear
  - 51.9.4 bodygear
  - 51.9.5 clothing ensembles
  - 51.9.6 materials for clothing
- **51.10 Personal equipment**
  - 51.10.1 visual equipment
  - 51.10.2 auditory equipment
  - 51.10.3 thermal equipment
  - 51.10.4 vibration equipment
  - 51.10.5 respiratory equipment
  - 51.10.6 body equipment
  - 51.10.7 equipment for altitude and depth
  - 51.10.8 equipment for space
- **51.11 Emergency services**
  - 51.11.1 rescue
  - 51.11.2 first aid
  - 51.11.3 evacuation procedures
- **51.12 Rehabilitation**

SOCIAL AND ECONOMIC IMPACT OF THE SYSTEM

52. TRADE UNIONS

53. EMPLOYMENT, JOB SECURITY AND JOB SHARING

54. PRODUCTIVITY
- **54.1 Absenteeism**
- **54.2 Turnover**
- **54.3 Strikes**
- **54.4 Economic consequences**

55. WOMEN AT WORK

56. ORGANISATIONAL DESIGN
- **56.1 Management**
- **56.2 Industrial democracy and goal setting**
- **56.3 Social interaction**
- **56.4 Industrial relations**
- **56.5 Information systems and communication**

57. EDUCATION

58. LAW

59. PRIVACY

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Anthropology Research Project

International Anthropometric Data

This data is based on over 50 foreign studies involving 23 different nationalities.

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- air force--1973
- army--1970
- civilian male and female pilots--1973
- military--1977

Bantu miners--1968

Canada
- air force pilots and navigators--1958,1961
- military--1975

Czechoslovakia
- civilian men and women--1969
- lumbermen--1969

England
- air force--1968,1973
- armoured corps--1973
- civilian women--1957
- guardsmen--1975
- navy aircrew--1968
- transport corpsmen--1976

France
- air force--1973
- army--1973
- men 17-22--1968
- navy--1973

Germany
- air force--1975
- office workers--1969
- tank crews--1965
- 20-year-olds--1970
- 25-40-year-olds--1972

Hong Kong
- Chinese military--1976

Iran
- air force--1970
- army--1970
- navy--1970

Israel
   aircrewmen--1981

Japan
   air force navigators--1972
   air force pilots--1965,1972
   civilian men and women--1974

Latin America
   armed forces--1972

NATO Military Personnel
   Greeks--1961
   Italian--1961
   Turks--1960

Netherlands
   civilian women--1951

New Zealand
   air force--1974

South Africa
   air force--1968
   army--1968
   navy--1968

South Korea
   air force--1967
   air force pilots--1961
   army--1967
   marines--1967
   navy--1967

Sweden
   aviators--1971
   civilian women--1968
   industrial workers (male and female)--1969

Thailand
   military--1964

United Kingdom
   Gurkhas--1976

Vietnam
   air force--1964
   army--1964
   marines--1964
   navy--1964

Summary of the PRODIS Databank

o Industrial examples

- registered measures	4.350
- documented measures	1.600

o Practical aids

- Information packages, reports	85

o Research projects

- Research reports	1.148
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- Research projects from the BMFT	1.000

o Literature items

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- Articles from Journals	4.800
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- Documentation from BAU	10.200
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- Special file for wage agreements	12.000

The contents of the database is equivalent to approximately 120.000 pages.

Cologne, Jan. 28, 1985

PRODIS-Controlled Vocabulary

1. ORGANISATIONAL DESIGN	process organisation operating sequence job analysis work task job evaluation job content	work organisation job design work study work system hours of work task subject	organisational structure management wages shift work transport
2. ERGONOMIC DESIGN	tools work place work area working environment stress strain	lighting fumes recovery fatigue gas climate	noise ventilation breaks product vibration dust radiation
3. TECHNICAL, TECHNOLOGICAL DESIGN	automation VDU computers information technology	mechanization micro electronics NC-Technology rationalization	robots engineering technology
4. OCCUPATIONAL SAFETY	safety at work occupational illness	protective measures protective equipment	accident prevention
5. PERSONEL	absenteeismus requirement training aptitude	fluctuation performance personel development personel department	qualification re-training employee suggestions scheme further education
6. LEGAL ASPECTS, GUIDELINES	company agreement recommendation	law standard	guideline collective agreement regulation
7. ECONOMIC ASPECTS	costs	profitability	
8. GROUPS OF PEOPLE	older workers foreigners	handicapped women	youths men pregnancy
9. SOCIAL RELATIONSHIP	atmosphere at work communication conflict	co-determination participation motivation	organisational design rehabilitation social behaviour satisfaction
10. SOCIAL ASPECTS	nutrition free-time	health provision social benefits	social policy
11. OCCUPATIONAL SCIENCES	anthropometry occupational hygiene occupational medicine occupational education occupational physi-ology	occupational psych-ology labour legislation occupational safety occupational sozi-ology work technology	labour economics occupational science biomechanics ergonomics

GENERAL TERMS (only in exceptions)

employer employee occupation worker council	research unions humanisation method	politics statistics environmental protection

CONTENTS FOR VOLUME I

CONTENTS FOR VOLUME II

PREFACE

In science, by a fiction as remarkable as any to be found in law, what has once been published, even though it be in the Russian language, is spoken of as known, and it is too often forgotten that the rediscovery in the library may be a more difficult and uncertain process than the first discovery in the laboratory.
LORD RAYLEIGH, 1884

The successful acquisition and interpretation of relevant information from primary source literature in perception and human performance can be a formidable task. This is due, in part, to the continuing growth and staggering volume of existing data and the manner in which it is organized topically and distributed physically over a wide number of individual journals and report media. The further removed an investigator's expertise from the objective of search, the more probable that important sources of data will be misinterpreted or missed entirely. Thus the effectiveness of direct access to the literature may be seriously constrained by the selection of appropriate key terms and the investigator's ability to discriminate "hits" from "false alarms" from the volume of potential sources related to the object of search.

Secondary sources, including textbooks, anthologies, and reference handbooks, such as this, provide an alternative basis for access to research data. As such, the worth of any source reference is inextricably tied to the individual user's trust in the author's objectivity and expertise in selecting and interpreting the subject matter. In the basic concept and design of this Handbook we have made a deliberate commitment to honor this trust. It is designed as a professional desk reference for the research psychologist or human factors practitioner in search of pertinent and reliable data on perception and human performance.

In his preface to the 1938 edition of *Experimental Psychology*, R. S. Woodworth reflected on the increasing difficulty of consolidating the burgeoning literature of experimental psychology. In mid-1980, we faced a nearly overwhelming dilemma of selecting the topics to include and exclude in planning the general outline for this Handbook. Numerous existing texts were reviewed for content and format of presentation. A primary consideration weighting our decisions was the potential applicability of the candidate topics to applied research and development. This choice of criterion was motivated by our basic conviction that many sensory, perceptual, and human performance data exist that are potentially useful to the human factors design of system controls and information displays. For various reasons, in part having to do with access and interpretability, these data have been relatively unexploited for purposes of application. We reasoned that the design of effective information displays, irrespective of sensory modality, must systematically take into account the variables that influence the display user's ability to acquire, process, and make control decisions regarding task critical information. Hence in this Handbook we have attempted to systematize and digest what is reliably known of the limits of these variables from the broader set of data resident within experimental psychology.

Although we sought to adhere to the criterion of "potential applicability" in selecting subject areas, many data found in this Handbook may be of questionable applied value. This is true for several reasons: first, we encouraged expanded treatment in some subject areas to provide a necessary perspective context in which applicable data might be interpreted. Conceptual issues that are highly theoretical have been included because of their prospective usefulness to design research and development in its basic phases. Indeed, we often doubted the reliability of our oracular skills and arbitrarily chose to bias selection on the side of inclusion. Section editors and authors were likewise instructed to bias their selection of data toward this notion of applicability in outlining the individual chapters. Nonetheless, we are guilty of excluding some research areas of potential applied value owing to oversight, lack of foresight, or our inability to attract the talents of the appropriate experts.

The problem, then, was to attract support for design of a reference Handbook of these data that we believed would satisfy a need by professional psychologists and provide a sound basis for follow-on data products geared specifically toward human engineering design applications. In December 1980, the Air Force Aerospace Medical Research Laboratory with major support by a consortium of DOD and NASA agencies initiated the Integrated Perceptual Information for Designers (IPID) project. This project was planned to be accomplished in several phases. In the first phase, resulting in this Handbook, we tried to produce a comprehensive though selective consolidation of data from a

range of subject domains within experimental psychology. In the second phase, we developed a presentation format for communicating these data to human factors psychologists and engineers for design applications. The product of this phase, the *Engineering Data Compendium. Human Perception and Performance* (to be published in three volumes by the Air Force), draws upon this Handbook for source material on perception and human performance, though it also encompasses a broader set of data drawn from the applied research literature on human/machine interfaces and systems design.

MAJOR FEATURES OF THE HANDBOOK

From the outset of this effort, it has been our view that the architecture of a professional-level reference Handbook must be founded on relatively independent, self-contained units of information that provide a detailed treatment of logical elements of the subject area. The benefit of this approach is that it allows for nondisruptive, in-depth treatment of branching issues that are subordinate to the main sequence logic of a chapter. This should be of significant value to the professional user seeking answers to specific questions, though not to the exclusion of the advanced student who is surveying the field. The accuracy and reliability of the data reported in this Handbook are of paramount concern to us. Each author was requested to carefully screen the data selected for treatment and to specify confidence limits wherever possible. Each chapter was then reviewed a minimum of six times by at least three different editors. In addition, many chapters were subjected to additional reviews by technical peers.

Related material in the Handbook and in other sources can be accessed through the abundant cross references, in-text citations, and reference listings. Those references marked by an asterisk (*) were selected as key sources of information by the authors and editors. Extraordinary efforts were taken to ensure the accuracy of each of these reference citations. In addition to a master table of contents at the beginning of each volume, there is a detailed table of contents at the front of each chapter.

The Handbook is profusely illustrated with data figures, tables, and schematics. Accompanying captions have been designed to be as self-contained as possible to enable basic interpretation by the informed reader without recourse to the text. In the same vein, the text draws upon the figures and captions to substantiate or illustrate the discussion without unnecessary digression to general experimental details. Overall, this has resulted in legends that treat the figures in considerably greater detail than commonly found in related texts. Whenever possible, figure and table captions contain a description of dependent and independent variables, an indication of the data's reliability, a "bottom line" summary of what the data are about, and a reference giving the source of the data. All figures have been plotted or converted and re-plotted using SI (Système International) units. We hope these features will add to the usefulness of the Handbook and the clarity of the in-text discussions.

ORGANIZATION AND SYNOPSIS

The Handbook is organized around seven major topical sections, encompassing 45 chapters and 7 overviews, presented in two volumes. Each major section was produced under the direct editorial supervision of independent section editors. Volume One, "Sensory Processes and Perception," provides a methodological basis for the Handbook followed by a data-oriented treatment of sensitivity in sensory systems and the perception of space and motion. Volume Two, "Cognitive Processes and Performance," deals with empirical issues in cognitive and human information processing followed by a treatment of factors in complex human performance.

Section I, developed as a collaborative editorial effort, provides detailed background on psychophysical theory and method in a chapter by J. C. Falmagne and one by G. Sperling and B. Dosher. With increasing reliance by experimental psychologist on computer-generated images as stimuli, the chapter by F. Freeman on "Computer Graphics" will be of considerable value to the reader as a methodological resource.

Section II, edited by D. MacLeod and J. Thomas, treat issues of basic visual sensitivity and eye movements. It begins with a chapter by G. Westheimer on the optical formation of the retinal image. The temporal variable is examined in the chapter on "Temporal Sensitivity" by A. Watson, and the spatial variables are the topic of the chapter on "Seeing Spatial Patterns" by L. Olzak and J. Thomas. The role of the wavelength variable is discussed in two chapters: "Colorimetry and Color Discrimination" by J. Pokorny and V. Smith and "Color Appearance" by G. Wyszecki. The chapter by D. Hood and M. Finkelstein on "Sensitivity to Light" also treats the wavelength variable in examining spectral sensitivity. In addition, their chapter treats the phenomena of adaptation, which collectively alter the absolute sensitivity of the visual system and its response properties with respect to temporal and spatial as well as spectral dimensions. The section closes with a compendium on "Eye Movements" by P. Hallett.

Section III, edited by C. Sherrick and R. Cholewiak, deals with sensitivity of hearing and the cutaneous, kinesthetic, and vestibular senses. In-depth treatment of the anatomical, physiological, and psychophysical aspects of these modalities is provided. Separate chapters by B. Scharf and S. Buus and by B. Scharf and A. Houtsma describe the structure, function, and qualitative and quantitative phenomena associated with the hearing sense. A chapter by I. Howard describes the vestibular sense in fine detail. The exquisite sensitivity and responsiveness of the kinesthetic system to varieties of strain and pressure are discussed in the chapter by F. Clark and K. Horch. An integrated treatment of the senses of the skin is provided by C. Sherrick and R. Cholewiak in their chapter on "Cutaneous Sensitivity."

Section IV, edited by H. Sedgwick, deals with the perception of space and motion by human observers. In the first chapter of this section, S. Anstis discusses sensory aspects of motion in the frontal plane. The goal of this chapter is to describe "some of the basic properties of the mechanisms by which motion registered by the visual system." Higher-order "Perceptual Aspects of Motion in the Frontal Plane" are then systematically explored by A. Mack. Next "The Perception of Posture, Self Motion, and the Visual Vertical" is detailed by I. Howard. Two other important parameters of motion perception are covered by D. Regan, L. Kaufman, and J. Lincoln in their chapter on "Motion in Depth and Visual Acceleration." L. Matin considers the "integration of retinal information with extra-retinal information about the position of the eye" in his chapter on "Visual Localization and Eye Movements." In the following chapter "Space Perception" H. Sedgwick discusses "how and how was the spatial layout of the environment is perceived." Next, "The Representation of Motion and Space in Video and Cinematic Displays" by J. Hochberg considers how characteristics of visual

perception enable compelling representation of three-dimensional motion "from a succession of two-dimensional displays containing no real motion." "Binocular Vision" by A. Arditi reviews the literature on the perceptual integration of information from the inputs of the two eyes. The ability of the observer to adapt in perceptually guided interactions with the environment is surveyed by R. Welch in "Adaptation of Space Perception." The last chapter of this section, by R. Welch and D. Warren, takes up the theme of the relations between the senses.

The chapters selected for Section V, "Information Processing," edited by M. Posner, reflect the information processing approach but do so with emphasis on the human performance of complex tasks. In his Overview, Posner defines the study of human performance as "a branch of experimental psychology that analyzes the skills involved in skilled performance, studies the development of skill, and attempts to identify factors which limit different aspects of performance." The chapter on "Visual Information Processing" by W. Chase stresses the elementary operations of visual codes. The processing of symbolic visual information—that is, "mental operations involved in forming visual, phonological and semantic codes of words and pictures"—is given comprehensive treatment in the chapter "Perceiving Visual Language" by T. Carr. "Auditory Information Processing" by H. Hawkins and J. Presson analyzes the role of attention in guiding the selection of auditory information with emphasis on the ability to sustain and share attention among different auditory levels. The relations between auditory information and speech are treated in P. Jusczyk's chapter on "Speech Perception." In the final chapter of this section, "Motor Control," S. Keele outlines "basic limitations on the speed and accuracy of simple movements" and shows how movements are assembled in memory as complex programs for the execution of tasks.

Section VI, "Perceptual Organization and Cognition," edited by M. Kubovy, addresses the multisensory elements of consciousness and how these affect our perception of form and pattern. The first chapter of this section, "Tactual Perception" by J. Loomis and S. Lederman, is concerned with "the sense of touch as a channel of information about objects and events outside the body." The next chapter, by D. Deutsch, provides an evaluative review of the literature on "Auditory Pattern Recognition." How the auditory system "parses," "groups," and "fuses" complex sounds into acoustic objects and events is the focus of this chapter. In the next chapter, I. Rock develops "The Description and Analysis of Object and Event Perception," providing in effect a Gestalt description of perceptual organization. "Spatial Filtering and Visual Form Perception" by A. Ginsburg follows, in which perceptual phenomena are discussed in terms of multichannel spatial filtering in the visual system. In a following chapter, "Properties, Parts, and Objects," A. Treisman integrates the research dealing with "decomposition of perceptual experience into dimensions and features, and the decomposition of objects and events into parts." "Theoretical Approaches to Perceptual Organization: Simplicity and Likelihood Principles" is the subject of the next chapter by J. Pomerantz and M. Kubovy. It focuses on the question of whether the visual system uses algorithms that maximize "regularity, homogeneity, and symmetry" to enable awareness of "the layout of the world." In the chapter "Visual Functions of Mental Imagery," R. Finke and R. Shepard review evidence for the "hypothesis that imagination and visual perception are functionally equivalent, and that under some conditions visual perception can be facilitated by mental imagery." The last chapter of this section, "Computational Approaches to Vision" by H. Barrow and J. Tenenbaum, provides a comprehensive treatment of methodology, data, and theory underlying concepts of machine vision.

Section VII, "Human Performance," edited by J. Beatty, deals with the measurement and characterization of human performance. This section addresses performance under task and environmental demands with more obvious practical implications for human factors engineering. The first chapter, "Effects of Control Dynamics on Performance" by C. Wickens, provides a lucid account of optimal control theory and measurement of the manual control task. N. Moray then "considers the role of the human operator as a supervisor or monitor rather than a direct controller." Next D. Gopher and E. Donchin provide a basic theoretical introduction to "Workload: An Examination of the Concept." This is followed by a detailed catalog of available "Workload Assessment Methodology" expertly consolidated by R. O'Donnell and T. Eggemeier. Next, theory and data on the maintenance of "Vigilance, Monitoring, and Search" for prolonged periods is treated by R. Parasuraman. This is followed by a review by R. Hockey of the experimental literature of the effects of noise, heat, anxiety, drugs, fatigue, and circadian rhythms on performance. The final chapter of the Handbook, "The Model Human Processor: An Engineering Model of Human Performance," by S. Card, T. Moran, and A. Newell, provides a model of transition between the theories of experimental psychology and the theories of human performance.

In all, there are a number of unifying themes that cross the boundaries of these sections. It would require a special essay to describe how the generalization of Muller's doctrine of specific nerve energies by Helmholtz laid the foundations for modern theories of color vision, and how this same idea, decorated with notions derived from Fourier analysis, led to modern theories of visual pattern perception and detection and shows signs of affecting theories of cutaneous sensitivity. However, such considerations transcend the purpose of this preface, which is designed simply to introduce this work.

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New York, New York
Los Angeles, California
March 1986

Expanded Table of Contents

Note: Only Sections 3.2 Binocular Vision and 4.1 Vibration and Display Perception are included in this prototype.

Section 1 Basic Sensory Characteristics

Section 2 Human Information Processing

Section 3 Visual Space Perception

Section 4 Human Performance

Section 5 Human-Machine Interface

Preface

This *Prototype Engineering Data Compendium* is a preliminary sample of the *Engineering Data Compendium*, which will be completed in 1986. Both are products of the Integrated Perceptual Information for Designers (IPID) project. The objective of the IPID project is to consolidate data on human perception and performance into a form useful to design engineers. To do this effectively, these publications have "human factored" the presentation of human factors data. That is, the content, conceptual organization, and physical format of this prototype document and the Compendium itself were established in a way that promotes efficient user access to the sought-after item of information.

Producing this prototype serves three functions. First, it is a tangible, substantive product which can be reviewed by prospective publishers. Second, the prototype will be integral to our on-going field evaluation project; the suggestions of design engineers and subject matter experts can yet be incorporated into the Compendium. Thirdly, this publication serves as an interim product for IPID's DoD and NASA sponsors. In addition to these ad hoc objectives, compiling the prototype was a trial-by-fire learning experience for members of the IPID project; it is hoped that its publication will reinforce their excellent efforts.

The prototype's organization is relatively simple. The Introduction describes the background and rationale of the project, details of the Compendium development process, and a description of the anticipated scope and content of the to-be-published *Engineering Data Compendium*. The User's Guide provides directions for accessing data from the Compendium and a description of the format and organization of information. The Specifications section includes a detailed description of the entry format, typesetting specifications, and packaging information.

The two technical sections, Stereovision and Vibration and Display Perception, represent the format's flexibility in covering various topics, as well as different categories of the literature (e.g., data, models, tutorials). In the front of each technical chapter is a Data Reference Card, containing a "roadmap" to direct the user, and index and glossary terms to acquaint the user with the section's most important concepts.

We hope that your review of this prototype excites you as much as it has those of us who have produced it. If you have any questions or concerns, please feel free to contact us about them.

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Introduction

In science, by a fiction as remarkable as any to be found in law, what has once been published, even though it be in the Russian language, is spoken of as known, and it is too often forgotten that the rediscovery in the library may be a more difficult and uncertain process than the first discovery in the laboratory.

Lord Rayleigh (1884)

The design of effective control and display systems requires consideration of the variables influencing the operator's ability to acquire and process task-critical information. The basic research literature contains a large body of relevant data regarding human perceptual and performance capabilities and limitations. Too frequently, however, designs have failed to capitalize on the skills of the operator or have made unreasonable demands on the user. The causes are twofold: first, the sheer volume of existing data makes it hard for psychologists and designers to review or keep abreast of all the relevant human perceptual and performance literature; and, second, the form in which these data appear makes it difficult for designers to access and interpret them.

The goal of the *Engineering Data Compendium: Human Perception and Performance*, produced by the Integrated Perceptual Information for Designers (IPID) Program, is to provide a comprehensive consolidation of human sensory/perceptual and performance data and to package these data so that they can be used as an effective resource by designers of simulators and operational displays and controls.

Over the last few decades, a number of attempts have been made to provide human factors data as a resource to designers (Tufts, 1952; Semple, Heapy, and Conway, 1971; Farrell and Booth, 1975, 1984; Shurtleff, 1980; etc.). Most of these efforts, however, have had less direct influence on the design process than their technical content alone would suggest. To help ensure that the *Engineering Data Compendium* finds its way to the designer's desk as well as the designer's bookshelf, efforts have been focused on tailoring the presentation of information to the needs of the user. In particular, systematic attention has been given during the development of the Compendium to: (a) defining approaches to effectively communicate human factors data to designers—that is, to determine appropriate presentation format, style, and terminology, and level of technical content; and (b) enhancing the accessibility of specific technical information relevant to design problems—that is, providing the user with a reliable and simple means for obtaining the specific data needed. Attention to these issues requires a clear definition of the user population (who they are, and how this information relates to what they do) and is critical to the use (or misuse) of human factors data by designers (see Devoe, 1963; Meister and Farr, 1966; Meister and Sullivan, 1967; Rogers and Armstrong, 1977).

In the development of the *Engineering Data Compendium*, we have learned from previous efforts in this area and have freely borrowed and integrated their successful elements into our approach. Nevertheless, the Compendium does have several unique features: one is the scope of the perceptual and performance data it seeks to make available to designers; another is the approach it has adopted in consolidating this information and presenting it so that it is both comprehensible and accessible to the intended user.

What the Compendium Contains

The available body of psychological research contains a staggering volume of human perceptual and performance data and principles that are of potential value to the design process yet are not systematically considered in depth by the existing human factors literature. This includes data regarding basic sensory capacities and limitations (contrast sensitivity, spatial/temporal eye movement dynamics, aural and vestibular thresholds, etc.), as well as perception and human information processing (visual, aural, and proprioceptive pattern recognition, information portrayal, etc.). In the *Engineering Data Compendium*, basic data and principles from these areas are treated in depth and combined with more applied human factors data into a single comprehensive reference source.

Eight basic kinds of information are included in the *Engineering Data Compendium*:

1. ***Basic and parametric data*** (e.g., dynamic range of the visual system, spatial and temporal contrast sensitivity functions, physical response constants of the vestibular system, receiver operating characteristic curves).

2. ***Models and quantitative laws*** (e.g. Fechner's law, CIE spaces, probability summation, operator control models). A model or law had to meet two criteria in order to be included: (a) it had to provide a way of interpolating or extrapolating existing data and relating them to a specific application, either to answer the design question directly or to specify the research needed to answer the question; and (b) it had to have a well defined and documented domain of reliable application.

3. Principles or nonquantitative or nonprecise formulations that express important characteristics or trends of perception and performance (e.g., Gestalt grouping principles, interrelationship between size and distance judgments, depth and distance cues).
4. Phenomena that are inherently qualitative or that are general and pervasive, although quantitatively described in specific instances (e.g., simultaneous brightness contrast, binaural beats, visual illusions, motion aftereffects).
5. Summary tables consolidating data derived from a body of studies related to a certain aspect of sensation, perception, or performance (e.g., table showing different acuity limits as measured with Landolt rings, grating patterns, etc.; tables summarizing the effects of various factors known to affect stereoacuity).
6. Background information necessary for understanding and interpreting data entries and models (such as rudimentary anatomy and physiology of sensory systems, specialized units of measurement or measurement techniques; specific examples are anatomy of the ear, geometry of retinal image disparity, colorimetry techniques).
7. Section introductions to topical areas that describe the topic and set out its scope, explain general methods used in the given area of study, note general constraints regarding the application of data in the area, and provide references for further general information.
8. Tutorials containing expository material on general topics such as psychophysical methods, Fourier analysis, linear systems analysis, sampling theory, etc., included both to help the user fully understand and evaluate the material in the Compendium, and to support research and evaluation studies in engineering development.

To make pertinent information more accessible to the user, graphic modes of presentation are used wherever possible. The Compendium contains over 1500 figures, including data functions, models, schematics, demonstrations of perceptual phenomena, and illustrations of methods and techniques. Other features of the Compendium include indicators of data reliability, caveats to data application, and the use of standardized units of measurement (International System of Units).

How the Compendium was Developed

The general approach of the IPID Program in developing the *Engineering Data Compendium* was based on the following assumptions:

1. Few individuals have in-depth expertise in more than one technical subarea. Since the domain of human perception and performance encompasses many specialized subareas, a large team of subject-matter experts is needed to ensure that basic data are appropriately evaluated in terms of their reliability, representativeness, and currency.
2. Basic research is motivated by concerns that are frequently very different from those of the design engineer who must apply the data. These differences are reflected in the manner in which these research findings are communicated and rationalized. This in turn, limits their accessibility and usefulness to design engineers. Furthermore, technical experts with basic research backgrounds rarely have an appreciation of the potential applications for these data in the design process. As a result, effective transmission of these data by direct means (i.e., from basic researcher to designer) is seriously constrained.

In the development of the *Engineering Data Compendium*, a three-step program was adopted to bridge this cross-disciplinary information gap with the aim of communicating potentially valuable basic data and principles to design engineers:

1. Credible *consolidation* of relevant data.
2. Comprehensible *presentation* of the data.
3. Reliable *accessibility*.

The first step was to cull, from among the huge volume of basic research literature, human perceptual and performance data that are pertinent for the design process. To accomplish this, subject-matter experts (those individuals who best understand the specific data) were employed to select, consolidate, and integrate basic research data into a first-level resource work—a specialized *Handbook of Perception and Human Performance*.

The second step was to present this data in a form usable to designers. For this, the information in the Handbook was distilled and translated into structured information units or entries presented in a validated format geared to the designer. These entries were then consolidated into the *Engineering Data Compendium*.

At present, access to the data is provided through the physical organization, indexing, and cross-referencing of information in the hardcopy Compendium. In the future, however, it may prove feasible to digitize the Compendium data base and implement automated access techniques.

To give the user some appreciation of the scope of this effort and the logic behind the development process, each of these steps is described in greater detail below.

Data Consolidation

Data Resources The first step in the development of the *Engineering Data Compendium* was to identify, collect, and consolidate sensory perceptual and performance data relevant to design requirements into a primary data resource (the *Handbook of Perception and Human Performance*). To accomplish this, the domains of sensation, perception, human information processing, and human performance were reviewed. Over forty technical subareas were selected for detailed treatment on the basis of their potential value to control and information display design (see Table 1a). A team of more than sixty recognized experts in these technical areas was assembled to compile the *Handbook of Perception and Human Performance*.

The Handbook is a professional-level reference work which differs from standard texts in its emphasis on empirical findings, its organization into self-contained units of information, its heavy use of data functions and schematics to present technical information, and its extensive indexing and cross-referencing. The Handbook will be published commercially by John Wiley & Sons in early 1986.

Not only was the Handbook a first-level data resource for the *Engineering Data Compendium*, it will also serve as a valuable supplementary reference for Compendium users, providing comprehensive reviews of technical subareas, useful background information, and more detailed treatment of selected empirical and theoretical topics. Appropriate cross-references in the Compendium direct the interested user to pertinent sections of the Handbook where given topics can be explored in greater depth.

In addition to the basic research subareas covered in the Handbook, a number of applied research subareas were considered of sufficient technical maturity to provide credible data input to the *Engineering Data Compendium* (see Table 1b). These subareas dovetail with those of the Handbook, extending the range of data into the applied research domain. Recognized experts in each technical subarea were recruited to identify data appropriate for the Compendium.

A. Handbook Technical Subareas

- Psychophysical Measurement
- Physiological Optics
- Sensitivity to Light
- Temporal Dimensions of Vision
- Visual Sensitivity to Spatial Patterns
- Color Vision and Colorimetry
- Color Appearance
- Eye Movements
- Vestibular Proprioception
- Cutaneous Sensitivity
- Kinesthesia
- Audition I: Stimulus and Threshold Sensitivity
- Audition II: Loudness, Pitch, Localization, Aural Distortion
- Simulating Space and Motion
- Perception of Object Motion
- Perception of Posture and Self Motion
- Motion in Depth and Visual Acceleration
- Eye Movements and Visual Direction
- Space Perception
- Binocular Perception
- Representation of Motion and Space in Video and Cinematic Displays
- Adaptation of Space Perception
- Intersensory Interaction
- Auditory Information Processing
- Speech Perception
- Visual Information Processing
- Perceiving Visual Language
- Motor Control
- Theory of Attention
- Analysis of Complex Patterns
- Object and Event Perception
- Perceptual Organization
- Modes of Dimensional Analysis and Combination
- Visual Form Recognition
- Auditory Pattern Recognition
- Tactual Perception
- Effects of Control Dynamics on Performance
- Monitoring and Supervisory Control
- Operator Workload
- Workload Assessment Methodology
- Vigilance, Monitoring and Search
- Changes in Operator Efficiency as a Function of Environmental Stress, Fatigue, and Circadian Rhythms
- Model of Human Performance

B. Applied Research Subareas

- Information coding, portrayal, and format
- Target detection, recognition, and discrimination
- Vibration and large amplitude motion
- Automation and allocation of functions
- Person-computer dialogue
- Feedback, warning, and attentional directors
- Operator-coupled dynamic control

Table 1

Data Selection and Validation The selection and validation of appropriate data items for the *Engineering Data Compendium* were accomplished through a series of structured reviews of the data sources and the candidate data items extracted from them. During the course of these successive reviews, the qualifications and background used as criteria to select reviewers shifted from expertise in the specific subject matter under review to experience with the conditions under which the information could be applied. This procedure assures that the information in the Compendium is not only accurate and up-to-date but also relevant to the design process and comprehensible to nonspecialists in the field.

Reviewers familiar with a specific topic area first reviewed information on that topic contained in the primary data source (the Handbook or applied literature) and selected candidate data items for the Compendium. A brief summary of each proposed data item, including data functions and original reference source citations, was then evaluated by at least three reviewers with expert knowledge in the subject area. Candidate data items were assessed for applicability (generalizability and usefulness for the design process), representativeness (soundness and currency of the data), and overall appropriateness for the Compendium. Reviewers were free to suggest alternative or supplementary data on the specific topic, recommend different organization or treatment approaches, as well as reject the proposed data item altogether as inappropriate for the *Engineering Data Compendium*.

Candidate data items which passed this review were processed into final entry format. Final entries were then re-evaluated by three reviewers, including an expert in the given subject area, a human factors specialist, and a member of the user population (design engineer). Entries were checked for:

1. Relevance: Will the information be useful to the target groups, or is it of purely academic interest?
2. Content: Is the basic information thoroughly represented? Is it accurate and accessible to the user community? Does it meet the requirements of the retrieval scheme?
3. Form and style: Does the entry adhere to the prescribed format? Is it written in clear and concise language?

This multi-step selection and review process for Compendium data items ensures that Compendium entries not only accurately represent the research data, but also relate to the practical concerns of the designer.

Data Presentation

Entry Format To help the user locate and interpret pertinent information, a standardized presentation format has been developed for entries in the *Engineering Data Compendium* which is tailored to the needs of the design engineer. This format has evolved over several years through an iterative process of review and discussion with the user community, sponsors, and consultants. In its present form, it represents our best attempt at "human factoring" the presentation of relevant perceptual and performance data.

The basic unit of information in the Compendium is the individual *entry* addressing a narrow, well-defined topic. Each entry is centered around a graphic presentation such as a data function, model, schematic, etc. Supporting text is compartmentalized into a set of text modules or elements. Each of these elements provides a concise subunit of information designed in content and style to support understanding and application of the data. The entry format is described in detail in the sections, "User's Guide" and "Specifications."

The prescribed entry format has the advantages of both formal structure and adaptive modularity. The appearance of entries is generally uniform. In almost all cases, entries are presented on two facing pages. The type of information contained in each titled text module is consistent across entries. Hence, the user can confidently access those elements needed to interpret or apply the data without being distracted by information irrelevant to the problem at hand. The format is also adaptable; only those elements appropriate to a given class or type of entry are presented.

General Organization Many schemes are possible as a basis for organizing and ordering the body of data in the *Engineering Data Compendium*. For example, the overall structure could be built around a conceptual theme such as the flow of information through the human perceptual system. The choice of organizational theme will, in turn, influence accessibility of specific information for a given user and design problem. Ideally, a scheme should be adopted that will enhance the opportunity for serendipitous access to relevant information. That is, the probability of a chance encounter of material related to the object of search is increased. To optimize this probability, it is necessary to understand clearly the assumptions underlying the "model" the design engineer uses to organize information when solving a design problem. Knowledge of this model should provide the basis for the overall structure of information in a given topic area. This macrostructure is, in essence, the skeletal framework on which the data entries are hung. Different macrostructures should reveal different patterns and gaps in current knowledge for specific technical domains. Understanding the logic underlying this general organization will provide a basis for interpreting these gaps in the emerging data base and will aid in identifying areas in which additional research is needed. In this prototype, entry topics are grouped into five major sections focusing on different aspects of human sensory/perceptual, information processing, and performance characteristics. A final compendium organization that is both consistent with the nature of the data and responsive to the needs of the design engineer is still being developed.

Data Access

The *Engineering Data Compendium* provides designers with a wealth of relevant human performance and perceptual data heretofore unavailable to them in a useful form. However, access to the data in the Compendium is complicated by the fact that the perceptual concepts which underlie these data typically fall outside the scope of the designer's previous training or experience. If these concepts are to be identified and recognized as relevant to specific design problems, they must be linked to information or issues familiar to the designer.

Several different methods of accessing material will be provided so that users with different interests, backgrounds, and levels of experience can not only determine what information in the Compendium is potentially relevant, but can also quickly and easily locate this information. These methods include the following (not all access tools are represented in this prototype).

1. ***Tables of contents:*** Two general tables of contents are provided at the front of the Compendium. One is a brief, global listing enabling the user to determine quickly the overall scope and organization of the Compendium. A second, expanded table of contents lists every subsection heading with the Compendium and allows the user to locate information on specific topics.

2. ***Sectional dividers and content listings:*** Each major section and topical area listed in the table of contents can be located rapidly by means of marginal tab dividers imprinted with the corresponding subject area titles. Immediately following each tab divider is a detailed listing of all the Compendium entries in the given subsection.

3. ***Data reference cards:*** At the beginning of each major topic section is a removable data reference card containing a branching logic diagram of all the entries in the given subsection as well as a keyword index to the subsection. These provide the reader with a structural overview of the topics covered in the subsection as well as rapid access to individual topic treatments. In addition, the reference cards contain useful supplemental information such as a brief glossary of abbreviations and technical terms used in the subsection.

4. ***High-resolution subject/keyword index:*** The index is designed to help both naive and experienced users formulate the design problem in terms of relevant perceptual issues which may then be directly accessed within the Compendium.

5. ***Cross references:*** Each Compendium entry includes extensive cross-references to other Compendium entries providing more detailed treatment of a topic or subtopic, discussion of related topics, or explanatory material to aid understanding or interpretation of the data, as well as cross-references to pertinent sections of the *Handbook of Perception and Human Performance* where additional information on the topic may be found.

6. ***Checklists:*** These lists suggest to the user various topics that should be considered in the development of specifications or designs. Included with each topic area in the checklist is an index to the Compendium section or sections where relevant data are provided.

7. ***Mission-related branching diagrams:*** This section allows the user to locate information relevant to specific mission elements. For example, if the mission is air-to-air combat, this section will refer the designer to data about the detection and recognition of moving targets (among other relevant topics).

8. ***Design- and equipment-related branching diagrams:*** This section provides access to the Compendium in terms of specific hardware or software features (e.g., display field of view, CRT raster line visibility). Features are organized according to the type of hardware involved. Within each feature section, each reference to a location in the Compendium includes a brief statement of why the material in that section is relevant.

In addition to these entry techniques, the following supplemental materials are included to aid individuals involved in specification or design:

1. ***Design examples:*** To make the application of the material in the Compendium more apparent, this section contains examples of typical display design problems and illustrates how the designs could be improved through the use of material from specific sections of the Compendium.
2. ***Tutorials:*** When necessary to ensure that the Compendium user understands the implications of the data and analysis in a particular topic area, background tutorial material is provided (e.g., psychophysical methods, stimulus specification techniques such as Fourier analysis, geometric schemes for describing eye position). This material is presented at a summary level and includes reference to publications where a more complete treatment can be found. There are two reasons for including this material: the user needs to know it in order to fully understand and evaluate the material in the Compendium, and it may support the use of research and evaluation studies in engineering development.
3. ***Glossary of technical terms, abbreviations, and acronyms:*** A Glossary is provided to reduce problems resulting from interdisciplinary vocabulary differences. For example, the terms "divergence" and "convergence" have different meanings for optical designers and visual scientists. For optical designers, the terms refer to the angular relationships either between principal rays or the rays within a single bundle, whereas for visual scientists, the terms are most generally used in reference to the angular relation between the visual axes of the two eyes.

State-of-the-art data access techniques are being pushed to their limits to ensure usability of the *Engineering Data Compendium*. However, the access techniques currentl available are insufficiently refined to guarantee reliable cross-disciplinary access to information. Furthermore, the use of a hardcopy medium places additional constraints on provision of easy and reliable data access

To provide a long-term solution to this problem, the IPID Program is assessing the feasibility of implementin an automated data access system based on current research in artificial intelligence and knowledge-based systems technology.

The development of a next-generation computerize knowledge-based management system will aid the engineer in acquiring and applying data relevant to a specifi problem with higher reliability. To achieve such a system three problems must be resolved. First, a "user friendly interface must be developed which allows communicatio in the language and at the level that is natural to the use Second, the system must help the user to formulate the objective of search. That is, it must help the designer ask the questions that need to be asked Last, within the retrieval process, information must be sorted and accessed as integrated solutions, probability estimates and recommendations.

A system having each of these functional characteri tics remains a concept for the future. However, current research in artificial intelligence is making headway in solving the basic issues which underlie this automated data management concept.

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range of subject domains within experimental psychology. In the second phase, we developed a presentation format for communicating these data to human factors psychologists and engineers for design applications. The product of this phase, the *Engineering Data Compendium: Human Perception and Performance* (to be published in three volumes by the Air Force), draws upon this Handbook for source material on perception and human performance, though it also encompasses a broader set of data drawn from the applied research literature on human/machine interfaces and systems design.

MAJOR FEATURES OF THE HANDBOOK

From the outset of this effort, it has been our view that the architecture of a professional-level reference Handbook must be founded on relatively independent, self-contained units of information that provide a detailed treatment of logical elements of the subject area. The benefit of this approach is that it allows for nondisruptive, in-depth treatment of branching issues that are subordinate to the main sequence logic of a chapter. This should be of significant value to the professional user seeking answers to specific questions, though not to the exclusion of the advanced student who is surveying the field. The accuracy and reliability of the data reported in this Handbook are of paramount concern to us. Each author was requested to carefully screen the data selected for treatment and to specify confidence limits wherever possible. Each chapter was then reviewed a minimum of six times by at least three different editors. In addition, many chapters were subjected to additional reviews by technical peers.

Related material in the Handbook and in other sources can be accessed through the abundant cross references, in-text citations, and reference listings. Those references marked by an asterisk (*) were selected as key sources of information by the authors and editors. Extraordinary efforts were taken to ensure the accuracy of each of these reference citations. In addition to a master table of contents at the beginning of each volume, there is a detailed table of contents at the front of each chapter.

The Handbook is profusely illustrated with data figures, tables, and schematics. Accompanying captions have been designed to be as self-contained as possible to enable basic interpretation by the informed reader without recourse to the text. In the same vein, the text draws upon the figures and captions to substantiate or illustrate the discussion without unnecessary digression to general experimental details. Overall, this has resulted in legends that treat the figures in considerably greater detail than commonly found in related texts. Whenever possible, figure and table captions contain a description of dependent and independent variables, an indication of the data's reliability, a "bottom line" summary of what the data are about, and a reference giving the source of the data. All figures have been plotted or converted and re-plotted using SI (Système International) units. We hope these features will add to the usefulness of the Handbook and the clarity of the in-text discussions.

ORGANIZATION AND SYNOPSIS

The Handbook is organized around seven major topical sections, encompassing 45 chapters and 7 overviews, presented in two volumes. Each major section was produced under the direct editorial supervision of independent section editors. Volume One, "Sensory Processes and Perception," provides a methodological basis for the Handbook followed by a data-oriented treatment of sensitivity in sensory systems and the perception of space and motion. Volume Two, "Cognitive Processes and Performance," deals with empirical issues in cognitive and human information processing followed by a treatment of factors in complex human performance.

Section I, developed as a collaborative editorial effort, provides detailed background on psychophysical theory and method in a chapter by J. C. Falmagne and one by G. Sperling and B. Dosher. With increasing reliance by experimental psychologists on computer-generated images as stimuli, the chapter by P. Freeman on "Computer Graphics" will be of considerable value to the reader as a methodological resource.

Section II, edited by D. MacLeod and J. Thomas, treat issues of basic visual sensitivity and eye movements. It begins with a chapter by G. Westheimer on the optical formation of the retinal image. The temporal variable is examined in the chapter on "Temporal Sensitivity" by A. Watson, and the spatial variables are the topic of the chapter on "Seeing Spatial Patterns" by L. Olzak and J. Thomas. The role of the wavelength variable is discussed in two chapters: "Colorimetry and Color Discrimination" by J. Pokorny and V. Smith and "Color Appearance" by G. Wyszecki. The chapter by D. Hood and M. Finkelstein on "Sensitivity to Light" also treats the wavelength variable in examining spectral sensitivity. In addition, their chapter treats the phenomena of adaptation, which collectively alter the absolute sensitivity of the visual system and its response properties with respect to temporal and spatial as well as spectral dimensions. The section closes with a compendium on "Eye Movements" by P. Hallett.

Section III, edited by C. Sherrick and R. Cholewiak, deals with sensitivity of hearing and the cutaneous, kinesthetic, and vestibular senses. In-depth treatment of the anatomical, physiological, and psychophysical aspects of these modalities is provided. Separate chapters by B. Scharf and S. Buus and by B. Scharf and A. Houtsma describe the structure, function, and qualitative and quantitative phenomena associated with the hearing sense. A chapter by I. Howard describes the vestibular sense in fine detail. The exquisite sensitivity and responsiveness of the kinesthetic system to varieties of strain and pressure are discussed in the chapter by F. Clark and K. Horch. An integrated treatment of the senses of the skin is provided by C. Sherrick and R. Cholewiak in their chapter on "Cutaneous Sensitivity."

Section IV, edited by H. Sedgwick, deals with the perception of space and motion by human observers. In the first chapter of this section, S. Anstis discusses sensory aspects of motion in the frontal plane. The goal of this chapter is to describe "some of the basic properties of the mechanisms by which motion is registered by the visual system." Higher-order "Perceptual Aspects of Motion in the Frontal Plane" are then systematically explored by A. Mack. Next "The Perception of Posture, Self Motion, and the Visual Vertical" is detailed by I. Howard. Two other important parameters of motion perception are covered by D. Regan, L. Kaufman, and J. Lincoln in their chapter on "Motion in Depth and Visual Acceleration." L. Matin considers the "integration of retinal information with extra-retinal information about the position of the eye" in his chapter on "Visual Localization and Eye Movements." In the following chapter "Space Perception" H. Sedgwick discusses "how and how well the spatial layout of the environment is perceived." Next, "The Representation of Motion and Space in Video and Cinematic Displays" by J. Hochberg considers how characteristics of visu

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